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Quarterly Progress Report

*Division 2*

Data Systems

15 August 1964

Prepared under Electronic Systems Division Contract AF 19(628)-500 by

## Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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# Quarterly Progress Report

*Division 2*

## Data Systems

15 August 1964

Issued 19 August 1964

### Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



## INTRODUCTION

This report reviews progress during the period 1 May through 31 July 1964 for the General Research Program of Division 2. Separate progress reports on the Ballistic Missile Re-entry Systems, Project Apollo and Project PRESS describe other work in the Division during the period. This results in separate reporting of all the work of Groups 21 and 22 and some of the work of Group 28.

Detailed reports of research will continue to be available in the form of Technical Reports, Group Reports, and Journal Articles. A list of the reports issued during the present reporting period is included here.

31 July 1964

F. C. Frick  
Head, Division 2

S. H. Dodd  
Associate Head

Accepted for the Air Force  
Franklin C. Hudson, Deputy Chief  
Air Force Lincoln Laboratory Office

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# UNCLASSIFIED REPORTS BY AUTHORS IN DIVISION 2

15 May through 15 August 1964

## PUBLISHED REPORTS

### Technical Report

TR No.				<u>DDC and Hayden Nos.</u>
346	The Orthomatch Data Transmission System	B. G. Kuhn	20 February 1964	DDC 602130

### Group Reports

No.				
1964-23	On the Accuracy and Resolution of Radar Signals	F. C. Schweppe	25 June 1964	DDC 601986 H-589
1964-24	A Short Description of the TRADEX Data Recovery System	O. V. Fortier P. J. Harris	5 May 1964	DDC 439260 H-576
1964-32	The Periodic Analysis of Sampled Data	E. Korngold	15 June 1964	DDC 601942 H-588

### Journal Articles\*

JA No.			
2123	On the Dynamical Equations of Conditional Probability Density Functions, with Applications to Optimal Stochastic Control Theory	H. J. Kushner	J. Math. Anal. Appl. <u>8</u> , 332 (1964)
2126	On the Optimum Timing of Observations for Linear Control Systems with Unknown Initial State	H. J. Kushner	Trans. IEEE, PTGAC <u>AC-9</u> , 144 (1964)
2130A	Scattering of Electromagnetic Waves from Dielectric Coated Conducting Spheres	J. Rheinstein	Trans. IEEE, PTGAP <u>AP-12</u> , 334 (1964)
2148	A Maximum Principle for Stochastic Control Systems	H. J. Kushner F. C. Schweppe	J. Math. Anal. Appl. <u>8</u> , 287 (1964)
2199A	Visual Search	U. Neisser	Scientific American <u>210</u> , 94 (June 1964)

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\* Reprints available.

Published Journal Articles (Continued)

JA No.			
2273	A Direct Constructive Proof of the Criterion for Complete Controllability of Time-Invariant Linear Systems	P. L. Falb M. Athans	Trans. IEEE, PTGAC <u>AC-9</u> , 189 (1964)
2291	A New Method of Measuring Small Radar Cross Sections by Digital Vector-Field Subtraction	P. C. Fritsch F. E. Heart*	Proc. IEEE (Correspondence) <u>52</u> , 628 (1964)
MS No.			
709	Optimal Control of Self-Adjoint Systems	M. Athans P. L. Falb R. T. Lacoss†	Trans. IEEE, Applications and Industry <u>83</u> , 161 (1964)
710	Minimum-Fuel Control of Second-Order Systems with Real Poles	M. Athans	Trans. IEEE, Applications and Industry <u>83</u> , 148 (1964)
995	Fuel-Optimal Singular Control of a Nonlinear Second-Order System	M. Athans M. D. Canon	Proc. Joint Automatic Control Conference, Stanford, California, June 1964

\* \* \* \* \*

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2310	The Relation of the Initial Costate to the Cost Surface in Optimal Systems	H. K. Knudsen M. Athans	Accepted by Trans. IEEE, PTGAC
2345	Searching for Novel Targets	U. Neisser R. Lazar‡	Accepted by Perceptual and Motor Skills
2362	On the Angular Resolution of Multiple Targets	J. R. Sklar F. C. Schweppe	Accepted by Proc. IEEE
2404	A $\lambda/4$ - and $\lambda/2$ -Shift-Method for Elimination of Unwanted Wall-Echoes in Radar-Anechoic Chambers	J. H. Halberstein	Accepted by Proc. IEEE
2415	On the Fuel-Optimal Control of Nonlinear Second-Order Systems	M. Athans M. D. Canon	Accepted by Trans. IEEE, PTGAC

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\* Division 6.

† Consultant.

‡ Author not at Lincoln Laboratory.

Unpublished Reports (Continued)

Meeting Speeches\*

MS No.			
726A	Optimal Control Theory	M. Athans	Gordon Research Conference, New London, New Hampshire, 13 July 1964
1043	A Method of Measuring Small Radar Cross Sections by Digital Vector-Field Subtraction	F. E. Heart <sup>†</sup> P. C. Fritsch	} Symposium on Radar Reflectivity Measurement, M. I. T., 2-4 June 1964
1044	The Spin-Drop Method of Measur- ing Model Radar Cross Section	P. C. Fritsch	
1052	The Lincoln Laboratory Model Backscatter Range	P. C. Fritsch D. F. Sedivec A. J. Yakutis	
1099	Implications of the Computer for Industry	I. E. Sutherland <sup>‡</sup>	Carnegie Conference, Carnegie Institute of Technology, 6 June 1964
1145	The Minimum Principle of Pontryagin and Its Applications	M. Athans	Symposium on Control System Optimization, Philadelphia, 1-2 July 1964

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\* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

<sup>†</sup> Division 6.

<sup>‡</sup> Consultant.

# ORGANIZATION

## DIVISION OFFICE

Frederick C. Frick, *Division Head*  
 Stephen H. Dodd, *Associate Head*  
 Jonathan T. Huntington, *Assistant*  
 James J. FitzGerald  
 Oliver G. Selfridge\*

### GROUP 21

Ovide V. Fortier, *Leader*  
 Leo J. Sullivan, *Associate Leader*  
 Leo C. Wilber, *Associate Leader*

E. Barsack	R. M. Martinson
L. E. Bird	E. J. Peters
G. Farrell, Jr.	D. F. Sedivec
A. H. Flink	D. J. Shannon
P. C. Fritsch	E. F. Tarbox
E. O. Gronroos	D. S. Turck
J. H. Halberstein	B. Ummel†
P. J. Harris	C. W. Uskavitch
R. M. Horowitz	F. S. Weinstein
H. L. Kasnitz	F. A. Wilson

### GROUP 23

Jack I. Raffel, *Leader*  
 Jack L. Mitchell, *Associate Leader*

A. H. Anderson	J. E. Laynor
P. E. Barck	C. S. Lin
H. Blatt	Lo, Yi-Chao Mei§
N. Cohler†	D. Malpass, Jr.
T. S. Crowther	W. J. Meyers
D. J. Eckl	C. E. Molnar*
A. G. Faulkner*	M. L. Naiman
J. Feldman	C. A. Norman
P. A. Fergus	S. D. Pezaris
C. D. Forgie	J. H. Reaves
J. M. Frankovich	L. G. Roberts
E. A. Guditz	D. R. Slutz†
J. S. Heart§	T. Stockham†
T. O. Herndon	W. R. Sutherland†
W. Kantrowitz	A. Vanderburgh, Jr.
K. H. Konkle	C. E. Woodward
C. J. Kury	

### GROUP 25

Warren S. Torgerson, *Leader*  
 Douwe B. Yntema, *Associate Leader*

J. W. Forgie	M. A. Morfield†
M. L. Groves	A. I. Schulman
W. P. Harris	G. M. Schulman
L. Klem	J. E. K. Smith
J. Lauterbach†	A. N. Stowe
C. K. McElwain	B. W. White
R. R. Mitchell§	R. A. Wiesen
R. T. Mitchell	

### GROUP 22

V. Alexander Nedzel, *Leader*  
 William Z. Lemnios, *Associate Leader*  
 Walter I. Wells, *Associate Leader*

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L. F. Cianciolo, Jr.	C. E. Nielsen, Jr.
D. F. Clapp	J. H. Pannell
E. L. Eaton	E. W. Pike
A. Freed	D. Reiner
A. A. Grometstein	J. Rheinstein
A. B. Gschwendtner	J. Salerno
J. H. Hartogensis	T. H. Savits†
R. C. Holland	B. J. Schafer
C. Hopkins	P. S. Schweitzer†
M. M. Klein	J. R. Sklar†
L. Kraff, Jr.	A. F. Smith
M. S. Macrakis	J. S. Strano†
M. H. Malone	J. L. Vernon
L. M. Meixsell	J. L. Warner
P. J. Mode†	P. A. Willmann
L. J. Murray	A. J. Yakutis
B. Nanni	

### GROUP 24

Donald O. Smith, *Leader*

M. S. Cohen	R. C. Johnston
R. W. Davies	C. T. Kirk, Jr.
K. J. Harte	L. Ladd†
E. E. Huber, Jr.	G. P. Weiss

### GROUP 28

Jack A. Arnow, *Leader*  
 John F. Nolan, *Associate Leader*

A. W. Armenti	D. A. Koniver
C. R. Arnold	J. B. Lewis
M. Athans	H. E. Meily
T. C. Bartee§	A. J. Morency
R. N. Davis	H. C. Peterson
P. L. Falb	F. C. Schweppe
L. A. Gardner, Jr.	J. Slesers
D. Hall†	J. M. Winett‡
D. L. Kleinman†	P. E. Wood, Jr.
H. K. Knudsen	P. M. Wortman†

\* Leave of Absence

† Summer Staff

‡ Staff Associate

§ Part Time

# DIGITAL COMPUTERS

## GROUP 23

### I. COMPUTER SYSTEMS

#### A. Curve-Drawing Scope

The curve-drawing CRT display unit has been connected to TX-2. It has performed satisfactorily with short computer programs which display points, lines, and simple parabolas. However, one of the more important performance criteria of any display system, the stability of the system under varied duty cycles, still awaits testing by a more sophisticated program.

#### B. New Counter Sequence

A new counter sequence, performing the function of either an alarm clock or a stop watch, is being designed. The counter will have a basic counting rate of 1 Mcps, with options to count all or certain specific computer instructions. It can also be used to time external or internal events, such as running time of a particular subprogram, or an instruction.

#### C. Optical Input

Although the results of tests on our image dissector camera system by ITT Industrial Laboratories showed several design deficiencies, the system was delivered to us in mid-April. Off-line testing has uncovered several other design errors, but more tests will be conducted before a detailed report will be sent to ITT. An effort will then be made to have them correct some of these errors. Meanwhile, some modifications are being made here, and hardware and software for on-line automatic testing are being debugged.

#### D. Multiuser Consoles

Wiring of the keyboard and typewriter sequencer has started. Construction of the consoles is near completion. Existing typewriter and dual keyboards from Lincoln Writers have been modified for compatibility with either system, and two new writers and keyboards, with a new case design, are on order. The use of the IBM Selectric (golf-ball) typewriter was temporarily abandoned due to difficulties in obtaining a type element containing the Lincoln Writer characters. Future consoles may use the Selectric if this problem can be solved.

#### E. Symbolic Page Address Transformation

Construction of the symbolic page address transformation system (SPAT) for TX-2 is well under way. The overlap of the transformation time and the core storage cycle time was altered so as to reduce the degradation in computer speed occasioned by SPAT from about 10 percent to less than 1 percent. The UNIVAC Fastrand file memory has been delivered and is being installed. The core memory expansion is now scheduled for September, and all the hardware changes to TX-2 should be completed within the next quarter.

## II. CIRCUIT DEVELOPMENT

### A. Circuits for SPAT

The high-speed arithmetic element test unit (AETU) circuits have been simplified and improved for use in the SPAT modification of TX-2. The new line of circuits uses two power supplies [+6.5 volt ( $\pm 10\%$ ) and -6.5 volt ( $\pm 10\%$ )], and has less power dissipation than the AETU circuits. Two new circuits have been added: a lower-speed level amplifier using diodes for input gating; and a variable delay circuit. Plug-in units for SPAT are being assembled and back-panel cabling is in progress.

### B. Integrated Circuits

An order has been placed with General Micro-electronics, Inc. for 400 integrated circuit elements to be used in the multiple typewriter modification for the TX-2 executive system, the V memory shaft encoder register, and a pulse tester for high-density magnetic film stacks. These will provide an opportunity to obtain some working experience with integrated circuit modules in operating systems.

### C. UHF Switching Transistors

#### 1. Germanium Planar Switch

A number of Texas Instruments germanium UHF switching transistors have been received and evaluated. These experimental devices have improved DC current gain and emitter breakdown voltage compared to those produced during the previous quarter. The frequency response is still lower than desired, but this should be considerably improved by the use of germanium of different resistivity.

#### 2. Microcircuits

Preliminary studies of several types of commercial microcircuits are under way. Photographs at 200 times are being examined carefully for flaws and defects. Measurements are made of individual component parameters, such as current gain and breakdown voltages between various diffusion layers, by scribing through metallization patterns (where necessary) to obtain isolation. An estimate of the subsurface structure is made from these data. So far, the small sample examined has shown a disturbingly large number of defects, most of which did not prevent operation of the device but, nevertheless, seem to indicate poor control and uniformity.

#### 3. Reliability

A series of intermittent failures in the AETU prompted a study of several types of silicon transistors. Heavy formations of "purple plague" were found in some instances, and poor bonds were encountered both on the chip and at the posts. The problem is under active investigation.

### D. Transistor Flip-Flop Memory

Word driver, memory plane, and digit output amplifier P.I.U. cards for the 64-word, 20-bit memory and the 16-word, 20-bit memory have been assembled, except for mounting the flip-flop

subassemblies. Approximately 1300 of the 1800 flip-flops have been received from the vendor; 500 have been tested and are ready for assembly on the memory plane card. A flip-flop testing jig for the T-2 semiautomatic tester has greatly speeded this part of the job. The card mounting frame has been assembled and aligned, layout of back-panel wiring for the two memories has been completed, and wiring of the back panel will begin immediately. A card tester has been designed and will be built. The finished memory will be checked out either with an assembly of logic units or through use of the FX-1 computer with special in-out connection.

### III. MAGNETIC FILM ENGINEERING

#### A. Substrate Cleaning

A multistep procedure for cleaning glass substrates has been selected and appropriate equipment for installation in the cleanroom has been ordered. The substrate-cleaning sequence consists of: an ultrasonically agitated aqueous detergent bath followed by a filtered and heated distilled-water spray rinse; a five-stage rinse in distilled, deionized, filtered water; alcohol drying; and an ultrasonically agitated Freon degreasing bath with Freon vapor rinsing and filtered air drying.

#### B. Fine-Line Pattern Generator

Requirements for the precision ruling of fine-line patterns have been determined and a precision layout table has been modified for the task. Diamond cutters are used to scribe lines in layers of silver chemically deposited on glass. Currently, line widths of 0.0005 inch and larger and several inches in length can be scribed. Lines are manually spaced by setting a precision micrometer; the cutter is automatically propelled to scribe each line. Adjustable stops provide for scribing lines of varying positions and lengths. Completed patterns will be photographically reproduced under cleanroom conditions to produce photoetching masters free from defects attributable to dust.

#### C. Characteristics of High-Density Configurations

Films evaporated from a 50-percent Co, 49-percent Ni, and 1-percent Fe melt have  $H_c \approx H_k \approx 25$  oe. At a thickness of  $700 \text{ \AA}$  (equivalent flux of  $1000\text{-}\text{\AA}$  Permalloy), these films will store in an open flux structure using 2-mil lines on 4-mil centers for both word and digit films. 100-ma digit currents and 600-ma word currents are typical.

Twice as much output is obtained with paired  $1000\text{-}\text{\AA}$  Permalloy (83-percent Ni, 17-percent Fe) lines requiring less current (20-ma digit current and 200-ma word current), but creep disturbing from fringing word fields restricts the total separation to 0.5 mil if 2-mil word lines on 4-mil centers are used. Digit lines in this case are 8 mils wide on 10-mil centers.

The use of a low  $H_k$  film as a saturable shield for a high  $H_k$  storage film has been proposed to provide a nonlinear element for two-coordinate word selection; initial experiments have successfully demonstrated this principle.

#### D. Content-Addressed Memory

A large number of measurements have been made of the film characteristics most significant for the proposed content-addressed memory. These measurements include (1) resistivity, (2) magnetoresistive effect, (3) nucleation threshold, (4) birotational output, and (5) power dissipation.

These results indicate that a match to mismatch ratio  $> 15:1$ , and signals  $> 1$  millivolt should be achievable. The extent to which these limits can be exceeded depends on decreasing (1) and increasing (2), (3), and (4), and (5) above. Experiments with various deposition procedures and with efficient heat sinking have given encouraging, though inconclusive, results.

#### E. Mechanical Design

The test fixture for substrates  $1.6 \times 10$  inches has been completed and is satisfactory. Individual air chambers over each substrate permit pressing the substrates tightly together for pairing, while allowing individual substrates to be removed and replaced without affecting the position of the remaining substrates.

A positioning device for the pulse testing of single-word and digit substrate pairs is being built. This will permit the testing of all locations on a word and digit substrate prior to installation in the memory system.

The rotating drum substrate holder and large vacuum system are now in operation, and successful depositions of copper and Permalloy have been made.

#### F. Page Address Memory

Initial checkout of the memory in FX-1 has been completed. Disturb margins are adequate, although some further checks will be made to obtain better correlation between the data taken on individual planes several months ago and the entire system as it now exists.

A sense amplifier incorporating a step-up transformer at the input, three stages of differential amplification, and regeneration in the strobe circuit will replace the amplifiers presently used. Tests have shown that this amplifier has reduced thermal noise and permitted faster recovery from the digit transient.

### IV. SYSTEM PROGRAMMING AND APPLICATION

#### A. Class-Oriented Ring Associative Language (CORAL)

CORAL is a set of M4 macro-instructions designed for the creation of data files as ring-structured tables, for data manipulation through flexible arrangement, and for variation of "ties" or "pointers." It is especially applicable to cases where there will be considerable categorization and recombination of data and where one set of data is strongly related to another. For example:

Electronic circuit simulation – graphical, electrical, and topological parameters.

Programming language conversion – flow diagram, symbolic manuscript, machine language code.

At this time, the CORAL system has progressed to a point where a fairly extensive set of macro-instructions are available for use. Further refinements will be made.

Class operations are now defined which permit the programmer to make statements about associations between classes and class members without being concerned with the internal ring structure, which is automatically set up for efficient operation of the system. It is now possible to declare a list, make master blocks, obtain and return free blocks of storage – all by direct statements. With the completion of the basic class manipulation and free storage statements, the CORAL language has now reached a state of usefulness, if not full refinement.

### B. Circuit Simulator

A circuit simulation program, using Sketchpad\* for display and graphical input, is being written and is nearly ready for demonstration. The circuit to be studied can be assembled under light-pen control from previously drawn and electrically defined component subpictures. The simulation uses difference equations and linear prediction for current splitting at each node. The resulting branch voltages are then checked, and if they do not balance within the specified tolerance, a new prediction is made. Usually, the first prediction is satisfactory. The incremental approach makes it possible to include nonlinear elements, e.g., tunnel diodes, and to specify unavailable, or even impossible, parameter values. The circuit can be modified graphically under light-pen control and the voltage and current at any point on the circuit diagram can be monitored on the display while the simulation is in progress.

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\* See I. E. Sutherland, "Sketchpad: A Man-Machine Graphical Communication System," Technical Report 296, Lincoln Laboratory, M.I.T. (30 January 1963), DDC 404549; also, Quarterly Progress Report, Division 2, Lincoln Laboratory, M.I.T. (15 May 1964), DDC 600838.

# COMPUTER COMPONENTS

## GROUP 24

### I. MAGNETIC FILMS

#### A. Magnetic Ripple and High-Speed Switching

The theory of the interaction between magnetic ripple and high-speed switching has been developed to the extent that strong predictions can be made regarding experiment. Experiments are presently in progress to check these predictions.

#### B. Ferromagnetic Circles

The Lorentz microscopy investigation of the domain configurations of Ni-Fe circles about 10 microns in diameter and 300 Å thick is being completed. Calculations show that the transition from a configuration with domain walls to a circular configuration occurs approximately at the diameters expected, if experimental values of the pertinent parameters are used. It is evident, however, that the demagnetizing energy in the domain-wall configuration is reduced by magnetization curling at the film edge.

#### C. Magneto-optics

An experimental program has been started to measure the  $[\epsilon]$  and  $[\mu]$  tensors in ferromagnetic metal films at optical frequencies. Special emphasis will be directed to the question of determining if  $[\mu]$  is gyrotropic. This is a particularly interesting question since gyrotropic  $[\mu]$  would presumably be due to optically excited spin-waves, a matter of considerable basic interest; furthermore, device theory shows that efficient magneto-optical light switches can be constructed from ferromagnetic metal films, provided that  $[\mu]$  is gyrotropic.

After the reflection or transmission of plane polarized light by a magnetic film, the rotation  $\rho$  and ellipticity  $\eta$  are characterized by the complex ratio of orthogonal field components  $\Theta = h_{||}/h_{\perp}$ . The off-diagonal elements of  $[\mu]$  and  $[\epsilon]$  can be separated by studying  $\Theta$  in the normal-incidence polar orientation (the light propagation vector  $\vec{s}$  and the magnetization  $\vec{M}$  perpendicular to the film surface). In order to measure  $\rho$  and  $\eta$ , an ellipsometer has been constructed from which an electrical output proportional to the angle between a nearly crossed analyzer and polarizer is obtained.\* The sensitivity and rapidity of measurement possible with this apparatus is great when compared with the usual visual methods. Extensive measurements and considerable data reduction will be required in order to carry out the determination of  $[\mu]$  and  $[\epsilon]$ .

#### D. Structural Dichroism

The electronic ellipsometer just discussed has been used to measure structural dichroism in magnetic films. The well-known oblique-incidence dichroism<sup>†</sup> is easily measured and, with

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\* S. J. Williamson and J. M. Weingart, J. Opt. Soc. Am. 54, 337 (1964).

† D. O. Smith, M. S. Cohen and G. P. Weiss, J. Appl. Phys. 31, 1755 (1960).

the increased sensitivity now available, more subtle effects are being investigated. Initial experiments suggest that magnetically-induced structural dichroism has been observed.

## II. ELECTRON TRANSPORT

### A. Contact Potential

The problem of obtaining multiple evaporations of aluminum mentioned in the previous quarterly progress report has been temporarily solved by the development of a tantalum evaporation boat protected by a thin outer skin of carbide (probably a mixture of silicon carbide and tantalum carbide). Preliminary data have been obtained with this source on the change of work function of aluminum undergoing oxidation in pressures of less than  $10^{-4}$  torr. The clean-surface contact potential between aluminum and gold can be obtained reproducibly within  $\pm 0.005$  volt on a given run for increasing thicknesses of aluminum, and this reproducibility permits a check to be made on the stability of the gold electrode during the oxidation process. The bare-surface contact potentials between aluminum and gold are not reproducible from run to run, however, and it is hoped that a new electron-beam evaporation gun will solve this problem.

Despite the bare surface, run-to-run nonreproducibility, the changes in contact potential with oxidation are reasonably consistent. With the ion gauge turned on, a continuous drift of the work function of aluminum to lower values is observed as the pressure of oxygen is increased. The changes are both pressure dependent and time dependent. Also, recently it has been observed that turning off the ion gauge could arrest the time dependence of the contact potential in the  $10^{-5}$  torr region. This suggests that ions produced by the gauge are dominant in producing oxide growth at low pressures. Further investigation of this effect will continue, and the electron-beam gun will be installed to try to achieve better reproducibility.

### B. Diode and Triode Fabrication

Pulse measurement of Al-Al<sub>2</sub>O<sub>3</sub>-Al diodes show pronounced Fowler-Nordheim tunneling and give unambiguous values of barrier height in the 1.4- to 1.6-volt range. Barriers previously rated up to 3 volts assumed an active area equal to the geometric area; the active area is apparently much less.

Diode breakdown is presently due to edge effects. It is planned to cover the edges of the first oxidized layer with an insulator such as calcium fluoride, with a resulting rise in breakdown voltage.

Thus far, the most reliable method of growing oxide tunneling barriers on aluminum in ultra-high vacuum (UHV) is to admit water-saturated O<sub>2</sub> at atmospheric pressure for 18 hours at room temperature. Changes in temperature, time, pressure, or water content have thus far produced poor diodes. Plasma oxidation in UHV systems has not yet been successful.

## GROUP 24

The following triode format is being worked on:

	<u>Å</u>	
Collector	2000	Au
Collector barrier	1000	CdS
Insulating bridge	1000	CaF <sub>2</sub>
Base	200	Al
Emitter barrier	~ 10	Al <sub>2</sub> O <sub>3</sub>
Insulating bridge	1000	CaF <sub>2</sub>
Emitter	2000	Al

### III. FILM-MEMORY SENSE AMPLIFIER

#### A. FX-1 Memory

The sense amplifier for the 1000-word FX-1 film memory has been modified to provide faster recovery and a lower thermal noise level. The circuit performed well in the memory and a complete changeover is now being made.

#### B. High-Density Memory

A 4-stage, conventional, single-ended video amplifier has been designed and tested using inexpensive components, including a transistor costing \$0.90. The circuit has a gain of 3000 and a rise time of 25 nsec. This approach is being evaluated for use with the high-density memory which will employ 350 sense amplifiers in the initial version.

# PSYCHOLOGY

## GROUP 25

### I. AUTOMATIC PROCEDURE EXECUTOR (APEX)

Work continues on the detailed specification and coding of all parts of the APEX, the executive program that will time-share TX-2 among several on-line users. Since the hardware for page addressing and program protection is now expected to be available at a later date than originally planned, the schedule has been changed to emphasize the earlier development of in-out routines and other parts of the system that can be checked out in considerable detail without the new hardware. Current status of the four major parts of APEX is as follows:

The Secretary, which handles input-output transfers and interrupts, has been fairly well specified. A large portion of the Lincoln-Writer programs are checked out and are operating in conjunction with a primitive version of the Maestro. Magnetic tape routines have been coded and are being checked out for temporary use as service routines in the existing M4 system. Work has begun on the Xerox routines, and some initial planning has been done for a composite device made up of a scope, a light pen, and a panel of pushbuttons.

The Maestro is the part of APEX that switches from one user to another, controls the interaction between users and in-out devices, and does the initial processing on system alarms and traps that indicate a user has violated the system rules. A primitive version of the Maestro has been checked out and is now operating with the Lincoln-Writer communication package. This program will be expanded to handle other in-out programs as they become available.

The Csar (core storage allocation routine) does the bookkeeping needed in sharing time, space, and programs. Flow charts for the Csar are nearly complete and coding will begin very soon.

The Mover transfers information to and from the auxiliary file memory. The UNIVAC Fastrand drum has now arrived and will shortly be available to test the basic Mover routines. In order to obtain experience with the file memory, the routines are being written to use in M4 as replacements for the TX-2 magnetic tape routines.

Preliminary plans are being made for some of the first of the user-oriented routines that will make use of APEX. Rough specifications for a group of routines to perform matrix arithmetic and plot graphs on the CRT are being considered.

### II. HUMAN INFORMATION PROCESSES

A final experiment concerned with the nature of subjective similarity has been completed. The stimuli consisted of a new set of 25 quadrilateral figures of equal area varying on two bipolar physical attributes. The subjects were required to rate the degree of similarity of all pairs. Earlier experiments suggested that spatial representation of similarity judgments for such figures would require four subjective dimensions: two quantitative dimensions accounting for unsigned degree of asymmetry of the two physical variables, and two trichotomous dimensions accounting for the sign (+, 0, -) of the corresponding asymmetries. Results showed that five dimensions are, in fact, required. Other things being equal, the four-dimensional representation requires that stimulus pairs differing in sign of asymmetry on both attributes be

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judged less similar than those differing in sign on only one of the two dimensions, a requirement not borne out by the data. The fifth dimension was required to correct for such discrepancies.

A study of cognitive behavior is under way in which three logically equivalent rules relate stimulus to response. The subjects are run under conditions of uncertainty, and both error and latency measures are taken. The initial results show clearly that the information processing varies systematically with the rule "programmed" into the subject.

Listeners in yes-no detection experiments must distinguish between intervals that do and do not contain a signal. Usually, the signal is an augmented stimulus, as when a brief tone is inserted into a noisy background. However, the signal may also be a diminished stimulus, as when a tone is briefly deleted from a noisy background in which it is normally present. Operating characteristics obtained from naive listeners revealed that a tone's deletion was harder to detect than its insertion. For Deletion, the detectability parameter  $d_s$  increased linearly with  $E/N_o$ , but the obtained slope of 0.034 was less than half as great as the characteristic slope of similar Insertion functions. Possible reasons for such poor deletion-detection are being explored, in view of the fact that an ideal observer performs equally well at Insertion and Deletion.

A further experiment has been performed on immediate serial recall of digits spoken very rapidly by a computer. It had been found earlier that recall becomes less accurate as the speed increases from two to ten digits per second. In the present experiment, speed was found to have less effect on recall of a list of six digits when the list was organized by presenting the first three digits to the left ear and the last three to the right. It was concluded that, during the presentation of a slow list, the subject has time to perform some sort of organizing process that becomes partially unnecessary if the list is organized for him.

### III. MAN-MACHINE COMMUNICATION

A practical technique has been developed by which an expert may indicate his evaluation of situations that have many variables, expressing his opinion in such a form that his evaluation of a new situation may be calculated. The effects of the variables need not be additive: the value that the typical expert assigns to a situation may be a nonlinear function of the sum of effects of the individual variables. The technique was developed in collaboration with members of the MITRE staff who were testing air-traffic control systems, and was used in scoring the final series of tests.

# CONTROL RESEARCH

## GROUP 28

### I. ON-LINE USE OF HYBRID COMPUTERS

A memorandum describing the hybrid computer development program has been prepared and will be issued shortly. The development of the computational facilities is outlined. The research applications and the programming of the facilities are described and several examples are given.

A method for automatically scaling a problem which is to be run on the second hybrid computer (LINC/DDA) has been developed.\* This method requires a connection matrix, which has been prepared by the user, and a set of bounds on the integrands as input conditions. It is then possible to determine whether a set of scale factors can be found and, if so, an "optimal" set is chosen using a linear programming algorithm which maximizes the total number of significant bits in the integrands. An automatic method is being developed for mapping a problem so that the combination of mapping and scaling can be used in a special compiler for the DDA.

A study of special scope display techniques for use with on-line computations has been started. The generation of displays which enable the user to see surfaces with the aid of a stereo viewer is being tried since many optimization problems would be aided by a three-dimensional display capability.

Design of the DDA is continuing and several special logic cards have been developed and tested. The core memory has been ordered and delivery is expected in September.

Investigations of design techniques using differential equation models and variational principles, and the development of recursive (difference equation) data-processing algorithms are continuing as indicated in the last quarterly progress report. The differential equation algorithm for detection and decoding of Gaussian signals has been documented.† A computational procedure‡ has been developed, suitable for implementation on a hybrid computational facility, for evaluating the accuracy and resolution of a broad class of radar waveforms. This class includes large time-bandwidth products and hypervelocity targets.

### II. DATA STORAGE AND RETRIEVAL

An initial general-purpose data storage and retrieval system is now operating [on the Project MAC Compatible Time-Sharing System (CTSS) from remote teletypewriters at the Laboratory]. At present, the programs allow the following operations on-line:

- Querying and selective search of the data files
- Interrogation of master files for descriptions of the present files and data association rules (relations)

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\*H. K. Knudsen, "The Scaling of Digital Differential Analyzers," not generally available.

†F. C. Scheppe, "Evaluation of Likelihood Functions for Gaussian Signals," accepted by Trans. IEEE, PTGIT.

‡F. C. Scheppe, "On the Accuracy and Resolution of Radar Signals," Group Report 1964-23, Lincoln Laboratory, M.I.T. (25 June 1964).

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Definition of new files and new relations between files

Specification of the punched-card format of data for inputting  
of new files

Once data are stored within this system, all user operations are in terms of his designated names for files, data fields, and relations; no formatting conventions must be remembered. The system is self-explanatory, with printed directions which inform the user what he must specify to search, modify, or redefine the files.

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